COMPACT WAVEGUIDE SPECTROMETER FOR MILLIMETER-WAVE REDSHIFT SURVEY

Interim or Finial Report

JPL Task 1011

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A. OBJECTIVES

In recent years, we have begun development of Z-Spec, a new broadband spectrometer for the far-IR-through-millimeter-wave regime. Z-Spec employs a technology we call the Waveguide Far-IR Spectrometer (WaFIRS), which is a new architecture that employs a diffraction grating in a parallel-plate waveguide and offers substantially reduced volume and mass relative to traditional grating spectrometers. It is therefore an excellent candidate for a flight instrument. We are constructing a cryogenic testbed for Z-Spec, which will be used for determining the redshifts of dusty galaxies, demonstrating the concept in a scientific setting.

The work on this project is both a technical and scientific pathfinder for JPL's and NASA's long-wavelength astrophysics flight programs. Significant progress has been made in FY02 and FY03, which is outlined in this report. (Note that this report is for FY02 and FY03 together)

B. PROGRESS AND RESULTS

The compact waveguide spectrometer called Z-Spec (BASS is the old name) is an ongoing effort incorporating contributions from many institutions worldwide with the full system design and integration centered at JPL / Caltech. Over the next two years, the ultimate goal is a demonstration of the new broadband spectrometer technology along with high-sensitivity direct detectors.

FY02 and FY03 has seen substantial progress on Z-Spec in all critical areas: design and construction of the new WaFIRS spectrometer module and its detectors and coupling structures, integration of the cryostat and 60mK refrigeration system, and development of the room temperature electronics. With the completion of the Bock laboratories late in FY03, the Z-Spec cryostat and hardware are in the process of moving to JPL, where the effort will continue.

The Grating Spectrometer

After the successful testing of our first prototype WaFIRS spectrometer, we have engineered the spectrometer module which will be used in Z-Spec. The heart of the design is a custom diffraction grating with 481 blazed facets (increased from the 401 in the prototype). In a WaFIRs spectrometer module, each grating facet is individually positioned to provide the best possible performance across the band, according to a numerical model. We have designed the grating surface to provide a resolving power between 250 and 400 across the band. Also critical are the parallel plates which confine the radiation and determine the relative geometry of the illumination horn, grating, and detectors. Because the entire spectrometer and plates will be cooled to less than 0.1 K, the mass must be minimized, yet the structure must be stiff to preserve the parallel plate spacing to 1 part in 100 across the ~55-cm structure. To satisfy this constraint, we have designed and analyzed ribbed parallel plates which integrate with a separately-machined blazed surface. These parts have been procured from an outside shop, the fabrication is complete, and they are receiving the final nickel and gold plate. Room temperature testing of this spectrometer will begin around Oct 1, 2003.

The Detector Assembly

Another key component is the detectors and their coupling structures. As part of the FY02 DRDF award, we have designed a SiN micromesh bolometer for Z-Spec, and the first batch of detectors have been fabricated in the JPL microdevices lab. Each of the 160 bolometers will be individually mounted in an alumina housing with its load resistors. The first batches of the detector housings and load resistors have been procured, mounted, and are quite satisfactory.

Because of the unique geometry of the waveguide spectrometer, we have had to develop a new method of illuminating the bolometers. After some design work using numerical E&M calculations, we have arrived at a solution in which each bolometer is illuminated with a waveguide bend, with half the detectors above and half below the plane of the spectrometer. These mitered bends are assembled in groups of 20, and the first block of 20 has been procured, fabricated, and received at JPL. The complete integration of this block, the spectrometer plates, the grating surface, the detectors and their housing will allow the first end-to-end cryogenic test of the spectrometer, to take place in early FY04. Subject to the results of this test, we will procure all of the mitered-bend blocks and the detector housings for the full 160 channels, and fabricate the detectors to operate the full spectrometer late in FY04.

The Cryogenics

The cryogenic system is an integral part of Z-Spec, and in the last year we have overcome the major obstacles in this area. Z-Spec is a cryogenic challenge because the entire spectrometer and its detectors are cooled to below 100 mK to reach the background limit for a R~300 spectrometer at λ=1 mm at a good mountaintop site. To provide this, we use two refrigeration systems: an adiabatic demagnetization refrigerator (ADR) to provide the ultimate low temperature, and a 3He—4He refrigerator to provide a cold sink at 350 mK which intercepts the parasitic thermal loads to the spectrometer. Both of these systems have been integrated and successfully tested. The 3He—4He refrigerator was contributed by Z-Spec collaborator Lionel Duband of the Service des Bass Temperatures, Grenoble, France. It provides a heat lift at 350 mK of more than 10 Joules in each cycle, and its operation has been completely automated as part of a custom software package. The adiabatic demagnetization refrigerator (ADR) was originally developed by Mark Dragovan, and has been cooled to 60 mK. It demonstrates more than 100 mJ of total heat lift below 100 mK. This will be adequate to cool the spectrometer and provide a hold time of around 1 day. The heart of the cryogenic system is thus in good shape and awaits the installation of the science spectrometer module with the first detectors in early FY04.

The Electronics

The warm preamplifier electronics are currently under development by JPL senior engineer John Battle. An overall systems architecture has been adopted, and circuit designs are being bread-boarded and analyzed.

C. SIGNIFICANCE OF RESULTS

Development and commissioning of Z-Spec represents a technical and scientific pathfinder for future far-IR space missions, including SAFIR, the Single Aperture Far-Infrared Observatory recommended by the Astrophysics Decadal Report of 2000. SAFIR is currently under study by teams at both JPL and Goddard Space Flight Center. Redshift measurements with Z-Spec at the large mm-wave telescopes will likely be a high-profile experiment, furthering JPL's position as an international leader in long-wavelength astrophysics. The experiment is a scientific complement to the efforts on SIRTF, Herschel, and Plank, and all are part of a long-term effort to position JPL in the leading role for future far-IR / submillimeter missions.

D. FINANCIAL STATUS

The total funding for this task was $149,000, all of which has been expended.

E. PERSONNEL

No other personnel were involved.

F. PUBLICATIONS

2 Papers were presented on Z-Spec / WaFIRS at the July 2003 SPIE Astronomical Instrumentation Conference:

Bradford, Charles M.; Naylor, Bret J.; Zmuidzinas, Jonas; Bock, James J.; Gromke, J.; Nguyen, Hien; Dragovan, Mark; Yun, Minhee; Earle, Lieko; Glenn, Jason; Matsuhara, Hideo; Ade, Peter A. R.; Duband, Lionel, IR Space Telescopes and Instruments. Edited by John C. Mather . Proceedings of the SPIE, Volume 4850, pp. 1137-1148 (2003).

Naylor, Bret J.; Ade, Peter A. R.; Bock, James J.; Bradford, Charles M.; Dragovan, Mark; Duband, Lionel; Earle, Lieko; Glenn, Jason; Matsuhara, Hideo; Nguyen, Hien; Yun, Minhee; Zmuidzinas, Jonas, Millimeter and Submillimeter Detectors for Astronomy. Edited by Phillips, Thomas G.; Zmuidzinas, Jonas. Proceedings of the SPIE, Volume 4855, pp. 239-248 (2003).